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The Effects of Habitat Use on the Round Goby, Neogobius Melanostomus, in the Lower Fox River and Lake Michigan.

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The effects of habitat use on the round goby, *Neogobius melanostomus*, in the Lower Fox River and Lake Michigan

by

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Introduction

Background

The Round Goby (*Neogobius melanostomus*) is a small species of benthic fish that is native to the Black and Caspian Seas of central Eurasia. In 1990, the round goby was introduced to North American waterways through the ballast water of large transport ships (Corkum, Sapota, & Skora, 2004). The round goby has spread from the St. Clair River, where it was originally introduced, into the Laurentian Great Lakes.

Figure 1. The Great Lakes Seaway where the round goby was originally introduced in 1990.

The invasion of the round goby into the Great Lakes is causing changes in the dynamics of the benthic food web. Lederer and colleagues (2008) noted that the abundance of round gobies has a direct correlation with decreased benthic macroinvertebrate abundance when a new site is invaded (Lederer, Janssen, Reed, & Wolf, 2008). Benthic macroinvertebrates provide an important food source for native benthic fish species such as the log perch (*Pericna caprodes*) and johnny darter (*Etheostoma nigrum*) (Corkum, Sapota, & Skora, 2004). Interspecific competition between the round goby and native benthic fish has had a negative effect on larger game fish in the Great Lakes. Popular game fish species, such as the yellow perch (*Perca flavescens*) and walleye (*Sander vitreus*) rely on a diet of native benthic fish that are competing with the round goby. Prey selection by the round goby on native fish larvae and eggs is having a detrimental effect on the reproductive success of other popular game species such as the smallmouth bass (*Micropterus dolomieu*) (Steinhart, 2004);(Corkum, Sapota, & Skora, 2004). The ecological effects of the round gobies' introduction to the Laurentian Great Lakes present a concern to the fish-based economies of the area that rely on native species.

The area surrounding the Great Lakes is invested economically in recreational and commercial fishing. Changes caused to the food web by the round goby have resulted in the reduction of some of the primary game fish populations which provide the large attraction for fishermen. Research by Raby et al. (2010) has shown that the location of round gobies in relation to the front of an invasion can affect the amount of prey available in a given habitat due to excessive feeding in established habitats (Raby, Gutowsky, & Fox, 2010). Their research also showed that prey selection varies with the size of the individual goby. They noted that smaller round gobies are more likely to feed solely on insect prey in opposition to larger round gobies which will include dreissenids in their diet (Raby, Gutowsky, & Fox, 2010). Another study by Ray & Corkum (2001) showed that round gobies were more likely to be located in habitats with rocky substrate. They noted that the habitat complexity of rock substrates corresponds to an increase in refuges. They also observed high site fidelity by gobies in rocky habitats and rapid dispersion of gobies in sandy habitats. Larger gobies actively displaced gobies in their study for the “best” rock or cobble spots in Lake Michigan (Ray & Corkum, 2001). In our experiment, we examined the effects of habitat use on the size of round gobies. We compared the length, weight, and age of gobies from Lake Michigan to those from the Lower Fox River to see if there was age-mediated distribution occurring in the river or if differences in size were related to resource availability.

One reason why the round goby has been such a successful invasive species is that it is a particularly hardy species of fish. The round goby is able to survive in a variety of temperatures which is part of the reason why it is able to survive as far north as it has been introduced. This species is also euryhaline, or salt tolerant (Round Goby, 2008). The round goby were able to be transported to North America from Eurasia in the ballast water of transport ships because of the species’ ability to tolerate all of the salinities to which it was exposed (Corkum, Sapota, & Skora, 2004). The voracious diet of the round goby was another major key in the expansion of the invasion front. The round goby is known to feed on a large diversity of prey, which made most habitats suitable in terms of resources (Lederer et al. 2008). Round goby are also known to reproduce rapidly in introduced habitats. In the span of the spawning season, from April to September, females can spawn up to six times depending on resource availability (Round Goby, 2008). Each egg clutch a female produces contains around 5,000 eggs that are defended and tended by the male goby (Round Goby, 2008). For these reasons, once the species was introduced to North America it quickly spread throughout the Laurentian Great Lakes and the surrounding tributaries like it did following previous introductions in Europe.

Habitats

The native home range of the round goby in Eurasia is the rocky areas of the Black and Caspian Seas. This species was also found in the larger surrounding river systems of Romania, Moldova, Bulgaria, Greece, Turkey and several other Eurasian countries. In recent years the boom in economic trade between countries has caused the range of the round goby to drastically increase through accidental transport. The round goby is now an invasive species throughout Europe and is even invading northern countries such as Sweden and Finland (Corkum, Sapota, & Skora, 2004). Since the species began invading new habitats in Eurasia, it has also been introduced to North America.

Figure 2. The original Eurasian habitat of the round goby the Black and Caspian Seas.

The Great Lakes of North America are a collection of large bodies of freshwater that are connected to the Atlantic Ocean through the Saint Lawrence Seaway and the Great Lakes Waterway. The lakes' centralized locations in the North American continent have made them a valuable pathway for transporting trade goods in Canada and America. The high amounts of trade in the area have introduced several other invasive species besides the round goby, including quagga (*Dreissena rostriformis bugensis*) and zebra mussels (*Dreissena polymorpha*).

<u>Figure 3.</u> The two invasive species of mussel introduced to the Great Lakes, the zebra mussel and quagga mussel. The zebra mussel is on the left and the quagga mussel is on the right.

The round goby is substrate specific when it comes to habitat selection. It is well documented that round gobies prefer rocky bottoms to sandy or muddy substrates (Lederer, Janssen, Reed, & Wolf, 2008) (Ray & Corkum, 2001). Ray & Corkum (2001) noted in their study on goby site affinity that adult round goby prefer sandy-stony substrates and mussel beds, while juvenile gobies occur near muddy-sandy substrates with abundant benthic flora (Ray & Corkum, 2001). Round gobies have expanded their invaded range to the Laurentian Great Lakes, tributaries of the Great Lakes, and branches of those tributaries. In the native range of the round goby, the species shows a habitat preference for lakes and large rivers. Kornis (2008) did a study on the Lake Michigan watershed to look at habitat selection in the round goby. Kornis noted that it is unique for an invasive species that normally lives in large open rivers and lakes to be moving into the smaller creek and stream tributaries as observed for the round goby (Kornis, 2008). Studies by several groups have shown that established round goby populations rapidly exhaust available benthic prey (Lederer et al., 2008);(Raby, Gutowsky, & Fox, 2010). The expanded habitat use by the round goby could be a response to decreased prey availability in other habitats.

Round Goby Morphology and Feeding

The round goby is a benthic species of fish, which means that it spends the majority of its time located at the bottom of its habitat. The anatomy of the round goby has developed in response to its benthic behavior. The round goby is adapted to benthic aquatic life through raised eyes and the lack of a swim bladder. The swim bladder is an air filled sac possessed by most fish that helps maintain and regulate buoyancy through inflation. Because the round goby has adapted to life without a swim bladder this species is unable to regulate their buoyancy and will sink unless swimming (Round Goby, 2008). The raised “frog-like” eyes of the round goby allow it to see the environment above and surrounding it. The lack of a swim bladder and raised eyes allow the round goby to remain close to the bottom of its habitat.

Figure 4. The round goby, a benthic species of fish with “frog-like” eyes, enlarged lips and a black spot located at the rear of the first dorsal fin.

The round goby is an opportunistic aquatic predator in its natural and introduced habitats. Round gobies are ambush predators that wait silently for prey to pass before swallowing the prey item. It uses a highly developed lateral line system and raised eyes to alert it to the presence of predators and prey that are in the surrounding area (Simonovic, Paunovic, & Popovic, 2001). Round gobies consume mussels, amphipods, chironomids, cladocerans, dragonflies, crayfish, mayflies, isopods, fish eggs, larvae, fish, and even members of the same species (Lederer, Janssen, Reed, & Wolf, 2008). Prey selection by the round goby varies based on season. In the summer the round goby is known to feed mainly on mollusks, amphipods, chironomids, and insect larvae. During the breeding season of other fish species, larvae and fish eggs form the majority of the diet (Lederer, Janssen, Reed, & Wolf, 2008). Round gobies have been noted to actively hunt fish eggs, even in nests where the species exhibits nest guarding behavior (Corkum, Sapota, & Skora, 2004). In the case of the smallmouth bass of North America, gobies will wait until the guarding male is disturbed before rushing at the nest to feed (**Fig. 5**). In one study done by Steinhart et al. (2004), male smallmouth bass nest guarding behavior was disturbed or the male was removed in order to see the rate at which round gobies consumed eggs (Steinhart, 2004). In one instance of feeding Steinhart et al. observed a group of gobies consume upwards of 2000 eggs and fish larvae.

Figure 5. Round goby feeding on smallmouth bass larvae while the defensive male is distracted and/or removed from the nest.

Round gobies are unique when compared to native benthic fish species because they will incorporate dreissenids into their diet. Adult round gobies have well developed jaw muscles that they use to feed on mussels in a process that involves consumption of the entire mussel. Between adolescence and adulthood, the jaw morphology of the round goby becomes more robust in order to withstand the strain of eating the shells of mussels (DeStasio, 2012). Despite the general belief that mussels form the majority of the round goby's diet, recent studies have shown that round gobies will actively select other prey items over mussels. The study by Lederer et al. (2008) found that in the introduced habitat of Lake Michigan, roughly 51% of the goby's diet was chironomids and 21% was amphipods, in opposition of dreissenids which only made up 5% of the selected goby's diet.

The round goby has had immediate impacts ecologically on the food web of the Great Lakes. Lederer et al. (2008) and Raby et al. (2010) both noted that in areas with goby presence, there have been drastic decreases in the populations of benthic invertebrates. In the Raby et al. study they found that in areas where gobies had already been established there was a lack of prey availability when compared to areas where gobies were currently invading (Raby, Gutowsky, & Fox, 2010). Chironomids and amphipods were the benthic invertebrates that were the most influenced by the round goby's presence due to heavy predation (**Fig. 6**) (Lederer, Janssen, Reed, & Wolf, 2008). The effects of the round goby on benthic macroinvertebrate densities influence the distribution and abundance of native benthic fish as well.

Figure 6. Benthic macroinvertebrates native to the Great Lakes that the round goby has begun to feed on (Lederer, Janssen, Reed, & Wolf, 2008).

Benthic invertebrates also represent the key prey of native benthic dwelling fish. Round gobies influence the composition of their invaded habitat through resource competition. Since being introduced to the Great Lakes the round goby has competed with native benthic species for the same food sources and habitat types (Corkum, Sapota, & Skora, 2004). The goby's large size in comparison with other species has allowed it to compete with many native benthic fish species for food sources and habitats. In the Raby et al. study they noted that the presence of the native benthic fish, the northern logperch (*Percina caprodes*) (**Fig. 7**), was significantly lower in habitats with an established goby population in comparison to the invasion front (Raby, Gutowsky, & Fox, 2010). The same trends in species abundance for other species such as the mottled sculpin (*Cottus bairdii*) (**Fig. 7**) have been seen in other habitats where the round goby has been introduced (Corkum, Sapota, & Skora, 2004). Native benthic fish species such as the mottled sculpin and northern logperch are unable to feed on dreissenid species resulting in direct impacts to these species when round gobies feed on other prey.

<u>Figure 7.</u> The mottled sculpin and northern logperch are native species of small benthic dwelling fish that rely on a diet of soft bodied macroinvertebrates. The mottled sculpin is on the left and the northern logperch is on the right.

Present Study

Our study looked at river and lake habitat use, size, and age of round gobies in the Fox River Watershed. Round gobies currently are only located in the Lower Fox River north of the Rapid Croche invasive species barrier and in Lake Michigan (**Fig. 8**). The Fox River, WI has been exposed to pollutants through the paper mill industry. The Fox River is a 200 mile river that flows through eastern Wisconsin north into Green Bay (Fox River (Wisconsin), 2013). The Fox River is generally divided into two distinct parts known as the upper and lower Fox Rivers. The Lower Fox River has a long history in the paper mill industry because of its proximity to Lake

Michigan. When removing runoff from the premises paper mills would let most chemical runoff enter the river and be carried downstream. The discharge of paper mills included Polychlorinated biphenyls or PCBs until the Clean Water Act of 1972. PCBs bind to the sediments in the Fox River; however, when ingested PCBs are toxic and can result in the deaths of animals and deformities of juveniles due to their effects on the development of the nervous system (Polychlorinated biphenyl, 2013). PCBs in the Fox River have resulted in regulations regarding the consumption of fish native to the Fox River and Lake Michigan.

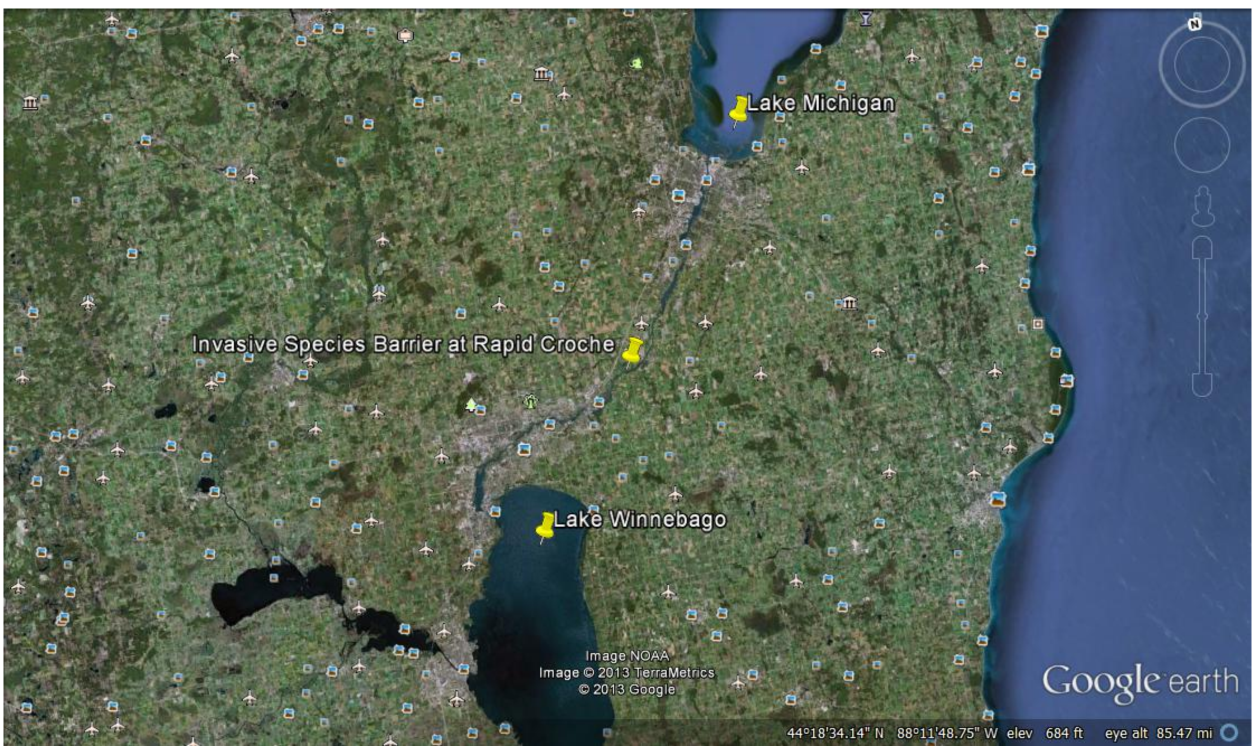


Figure 8. The Lower Fox River that flows from Lake Winnebago north to Lake Michigan. The invasive species barrier located at Rapid Croche prevents round gobies and other introduced species from traveling upstream.

The Lower Fox River is divided by a barrier located in Wrightstown, WI known as the invasive species barrier that was put in place in order to prevent newly introduced species from being introduced to Lake Winnebago, WI. The river was originally open to recreational boat travel until 1986 when the established lock system was closed and the invasive species barrier was erected in response to the sea lamprey (*Petromyzon marinus*) (DeStasio, 2012). The barrier, in combination with the river lock system, acts as a way to prevent invasive species from traveling from Lake Michigan to Lake Winnebago. Lake Winnebago is the largest freshwater lake located in Wisconsin and is part of a large four lake chain that includes Lakes Poygan, Winneconne, and Butte des Morts and is connected by the Fox and Wolf Rivers to Lake Michigan (Lake Winnebago, 2013). Lake Winnebago is considered by many to be some of the best fishing in Wisconsin, if not the country, for walleye and lake sturgeon (Acipenser fulvescens) because of the large natural populations. Recreational fishing is highly prized in the area surrounding Lake Winnebago, with current estimates stating that roughly $300 million is spent on fishing annually (Lake Winnebago, 2013). There has been discussion amongst the human population of the Fox River Valley about opening the lock system along the Fox River in order to allow boat travel between Lake Michigan and Lake Winnebago. Based on previous introductions of the round goby to new habitats, there could be a negative shift in the ecological and economic dynamics of Lake Winnebago if it is exposed to this species.

The objective of this study was to collect round goby from several sites along the Fox River and the eastern coast of Green Bay, Lake Michigan and measure length, weight, and age in order to see how habitat use affected size or if habitat use was age-mediated. We hypothesize that round goby in the Lower Fox River represent younger members of the species than the individuals collected from Green Bay and are smaller because of difference in age, not food resources. This study is focused on understanding changes in round goby habitat use between two habitats through distribution and size dynamics.

Methods

Sites

Round goby were collected from three sites in the Lower Fox River and two sites in Green Bay, Lake Michigan for size and age data. The study sites used were selected based on prior round goby sampling that occurred from June 10 through July 14. The sites selected for study were Plum Creek, Apple Creek, FR-4, Little Sturgeon Bay, and Chadouir's Dock. Individuals were collected from each site from July 16 to October 23 with sampling occurring several times a week during the months of July and August. From September through October sampling effort was reduced to once a week. Sampling ended in October due to a lack of goby presence during sampling efforts.

The site at Plum Creek was located off of the Washington St. bridge in Wrightstown, WI where the mouth of Plum Creek connects to the Lower Fox River (N 44O 19.238', W 88O 10.531'). The area surrounding the site was moderately developed, with a nearby parking lot and boat launch for recreational use. There was rocky habitat along the banks of Plum Creek's mouth due to a bridge that crossed at this point. The rest of the benthic substrate consisted of mud and detritus from overhanging foliage and had a steep slope towards the middle of the creek. This site was accessed on foot.

Figure 9. The sampling area and surroundings of the site at Plum Creek.

The site at FR-4 was located along the banks of the Lower Fox River near Wrightstown, WI (N 44O 18.947', W 88O 11.413'). The site was downstream of the Wrightstown dam and invasive species barrier. The area surrounding the sampling site had some moderate development in the form of river front housing. The actual sampling site was not directly in front of any housing. The substrate at FR-4 was sandy with intermixed mud and the banks of the river at this site were shallow and extended for some distance. The banks of this site were also covered in vegetation in the form of trees. A boat had to be used in order to reach FR-4 due to the thick vegetation along the banks and surrounding housing.

Figure 10. The sampling area and surroundings of the site at FR-4.

The site along Apple Creek is located by the bridge on Lost Daulphin Rd. north of Wrightstown, WI. Other than the bridge near the site, there was no development around this area. This site is a tributary of the Lower Fox River and had cobble substrate. The creek at the sampling site was shallow and had a slow flow rate with heavily forested banks. This site was accessed on foot.

Figure 11. The sampling area and surroundings of the site at Apple Creek.

The site in Little Sturgeon Bay was very developed, with three large concrete docks that extended roughly 9 to 12 m. Between each of the marinas were concrete boat launches. The water depth was between 1 and 2 m until the end of the docks where it quickly deepened. The shallow area had a sandy substrate with no vegetation. Next to the docks there was an area with cobble substrate and several larger rocks. This area was slightly deeper than the dock area and had a vegetated bottom as well. This site was accessed by foot.

Figure 12. The sampling area and surroundings of the site at Little Sturgeon Bay.

Chadouir's dock is a park located in Brussels, WI. It was another somewhat developed site with a marina and boat launch located nearby (N44°44.240', W87°46.180'). The actual site was a manmade island that was reached by crossing boulders that stuck out of the water. The island was a tall concrete structure surrounded by a sandy substrate with a few rocks and vegetation. The location also had a high density of zebra mussels as well. It was a relatively shallow site with a water depth less than 1 m throughout most of the location and was reached on foot.

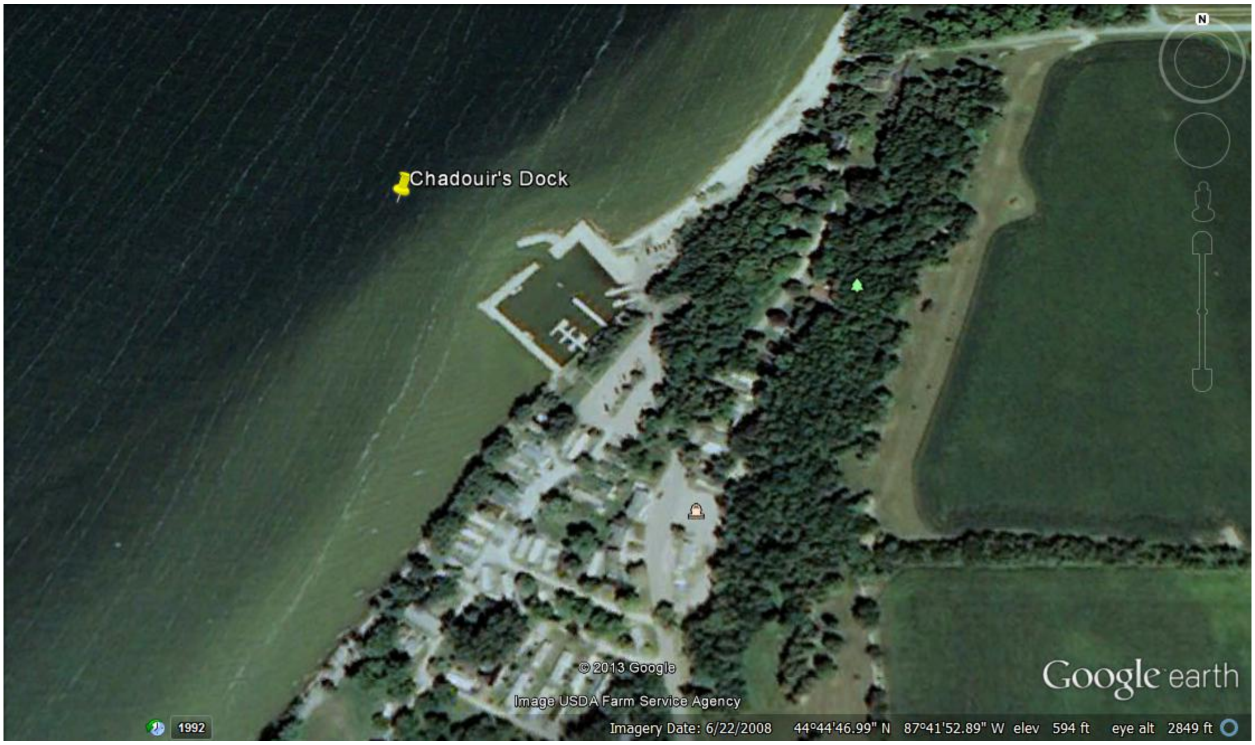


Figure 13. The sampling area and surroundings of the site at Chadouoir's Dock.

Specimen Collection

Specimens were collected from Plum Creek, FR-4, and Apple Creek using Gee-style steel minnow traps. The methodology for using the minnow traps was the same as that used by Kornis (2008). The traps we used had the specified mesh size of 6mm with openings that were 30mm in diameter. The traps were then baited with thawed chicken liver and set near rocky substrates in order to increase chances of collecting goby (Kornis, 2008). Traps were left at each site overnight and then recovered the next day.

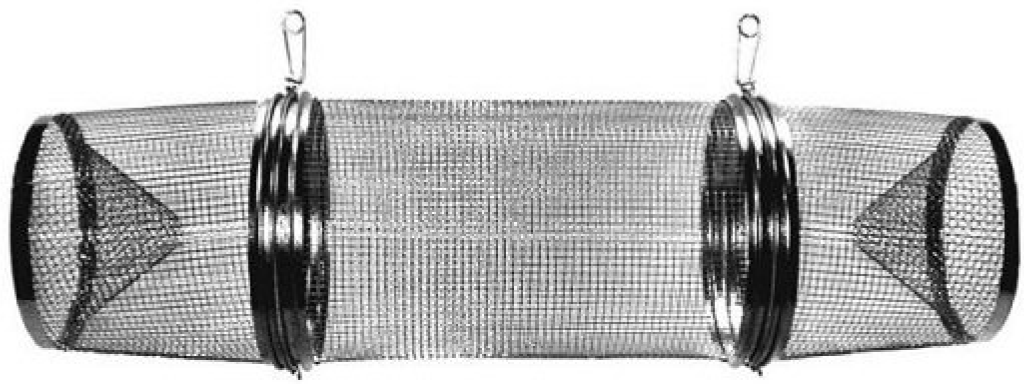


Figure 14. A steel Gee-style minnow trap that was used in overnight sampling.

FR-4 and Apple Creek were sampled using a battery-powered backpack electrofishing unit. The settings used for the unit were based on those described by Kornis (2008). The rate and duty were set to 90 and 100 in order to have a collective focus on smaller fish (Kornis, 2008). Due to the high conductivity of the Lower Fox River we set the voltage setting to stay around 4 amperes. We sampled each site in 20 minute intervals working upstream from one bank to another in Apple Creek and parallel to the bank at FR-4.

Figure 15. Electroshocking was done in teams of three, with two side researchers to netting and one researcher in the middle using the backpack electorshocking unit.

FR-4 was also sampled using a beach seine. The seine was used in groups of three people with two people walking the edges of the seine towards shore and a third person helping with any snagging that might occur. Once the seine was pulled up at the shore, the third individual would examine the caught fish and collect any round goby in the sample.

All sites were also sampled using hook and line methodology. The hooks used were size 8 in order to allow goby of a variety of sizes to be caught. The hooks were then baited with either earthworms or chicken liver.

Once a goby was collected it was placed in a plastic bucket so sampling could continue. When we had finished sampling a site the bucket was brought back to a van where an air stone, powered by a car adaptor, would be placed in the bucket to provide sufficient oxygen as we transported the fish back to the lab. At the lab goby specimens were euthanized in tricaine methanesulfonate (MS-222) and placed in a whirl bag that was labeled with the date and sampling site. The bag was then placed in the freezer in order to preserve the collected goby.

Data Collection

Data collection was done from January 14 to February 25. The specimens were thawed in their bags by putting them in a warm water bath. This method allowed several sites worth of goby individuals to thaw while preventing intermixing. After the goby in a bag had thawed, individual total length data and weight were collected in centimeters and grams respectively. Size and length data was collected from a total of 64 fish. Scales along the lateral lines of 26 goby specimens, below the dorsal fin, were then collected and placed in an envelope for later analysis. Each goby was then assigned a specific label on its envelope based on the location where it was caught, a specimen number from that site, and the time of collection. This was done in order to make sure that the size data could be matched with the age data of the specific fish collected.

Individual round goby were aged into one of five different age groups based on the methodology used by Grul'a et al. (2012). Scales were spread along a microscope slide and flattened by placing another slide on top. The two slides were then taped together in order to keep the slides from moving and to keep pressure on the scales. The tape at one end was then labeled with the specific name of the fish from which the scales were taken. The scales were then placed under an optical microscope for annuli analysis (Grula, Balazova, Copp, & Kovac, 2012). Scales were located using the x4 magnification and then examined using x10 magnification. Age of the fish was determined by examining the number of fully developed annuli observed on each scale, moving outward from the nucleus. Multiple scales were examined from each fish with age being derived from the mode number of developed annuli. The number of scales counted and age of the fish were recorded. Individual fish were then placed in one of five age groups from 0 to 4 (Grula, Balazova, Copp, & Kovac, 2012).

Figure 16. A prepared slide containing multiple scales flattened between two slides taped together with scotch tape and labeled with the individual's ID.

Data Analysis

The length and weight relationship was also quantified by solving for Fulton's Condition Factor of all 64 fish used in the study. The condition factor is a measure of the wellbeing of an individual fish. This factor is influenced by degree of nourishment, age, and in some species sex of the individual fish. In order to determine the condition factor we used the equation:

$$C=1{,}000W/L^3$$

The condition factor equation is a measure is the equivalent of the weight of the fish (g) times 1000 divided by the length of the fish (cm) with the growth rate as an exponent. We determined the growth rate to be 3 from the equation of the lines in **Figure 21**.

We ran two sample t-tests assuming unequal variance on the length, weight, and condition factor of the fish we had collected from the two habitat types with an alpha level of $P = 0.05$. This was done using the data analysis tool pack extension available through Microsoft Excel. We selected the data from the goby in Green Bay, Lake Michigan as representative of variable one and those from the Lower Fox River as variable two.

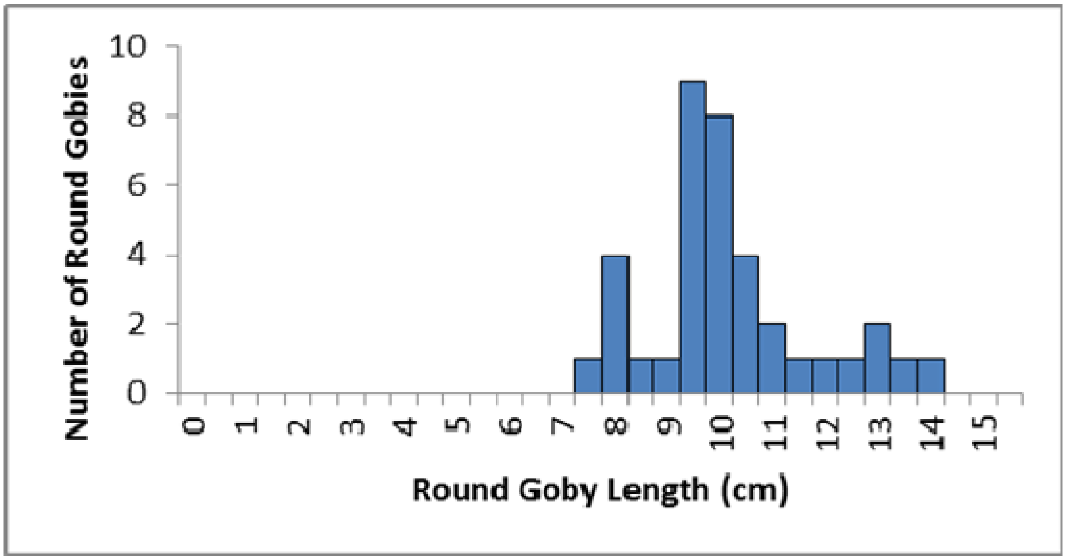
Some of our values we ended with were not distributed normally. In order to account for this in our analysis we also ran the Mann-Whitney U test on the length, weight, and condition factor of the fish as well. The Mann-Whitney U test has a greater statistical robustness than the t-test in cases where there are mixed or non-normal distributions like we observed in some cases. This test was similarly performed using an Excel module developed by

MacDonald (2009) that allowed one to simply copy and paste data into the spreadsheet for analysis.

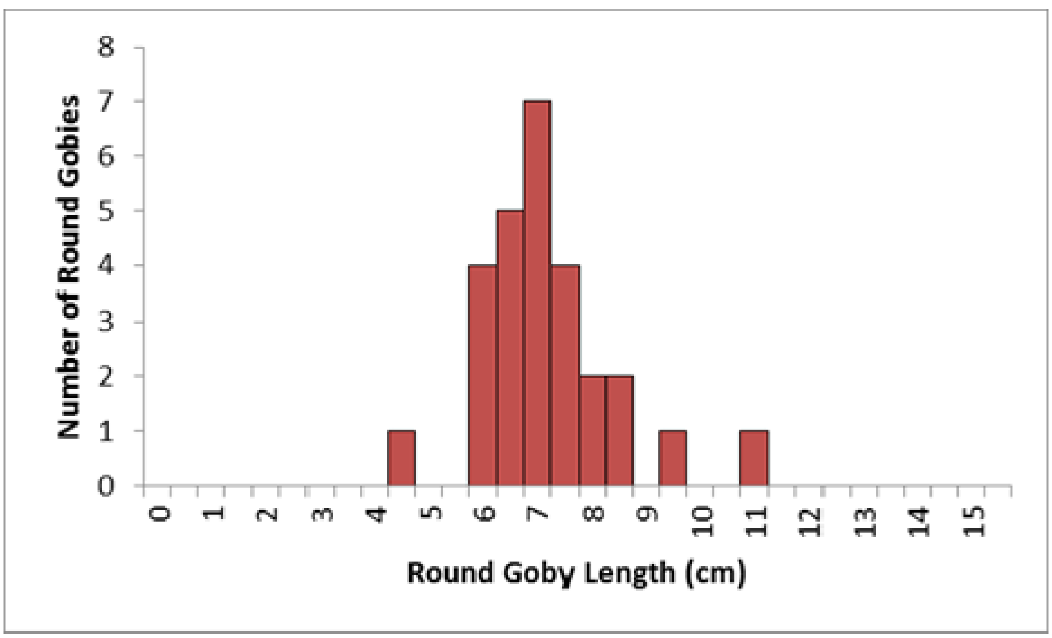
Results

Length

The group of round goby collected from the Lower Fox River were often shorter than the individuals collected from Green Bay, Lake Michigan (**Fig. 17 & 18**). Round goby in Lake Michigan ranged in length from 7.5 cm to 14.5 cm. The most frequent lengths of gobies from sites in Lake Michigan were between 9.5 cm and 11.5 cm (**Fig. 17**). The gobies collected from the Lower Fox River ranged from 4.5 cm to 11.5 cm in length (**Fig. 18**). The majority of round gobies collected in the river ranged between 6 cm and 9 cm. A T-test of the difference in average lengths between the two habitats showed that the animals from Green Bay were statistically significantly longer than those from the Lower Fox River in the differences of length between the two habitats (P=3.28E-12). A Mann-Whitney U test resulted in confirmed a statistically significant differences as well (P=1.61357E-09).



<u>Figure 17.</u> A histogram of the frequency of round goby from Lake Michigan at a specific length.



<u>Figure 18.</u> A histogram of the frequency of round goby from the Lower Fox River at a specific length.

Weight

Fish collected from Lake Michigan tended to be heavier than their counter parts from the Lower Fox River (**Fig. 19 &20**). Gobies from Lake Michigan ranged in weight from 4.5 g to 33 g. The most frequent goby weight in Lake Michigan was between 11 g to 12 g. Those collected from the Lower Fox River ranged in weight from 0.5 g to 10.5 g (**Fig. 20**). The largest frequency of gobies in the Lower Fox River were between 2.5 g and 3.5 g in weight. The T-test and Mann-Whitney U test used to compare weight differences in the two habitats both showed that the Green Bay fish were significantly heavier than those from the Fox River (T-test P=3.27811E-12/ Mann-Whitney U P=2.46745E-10).

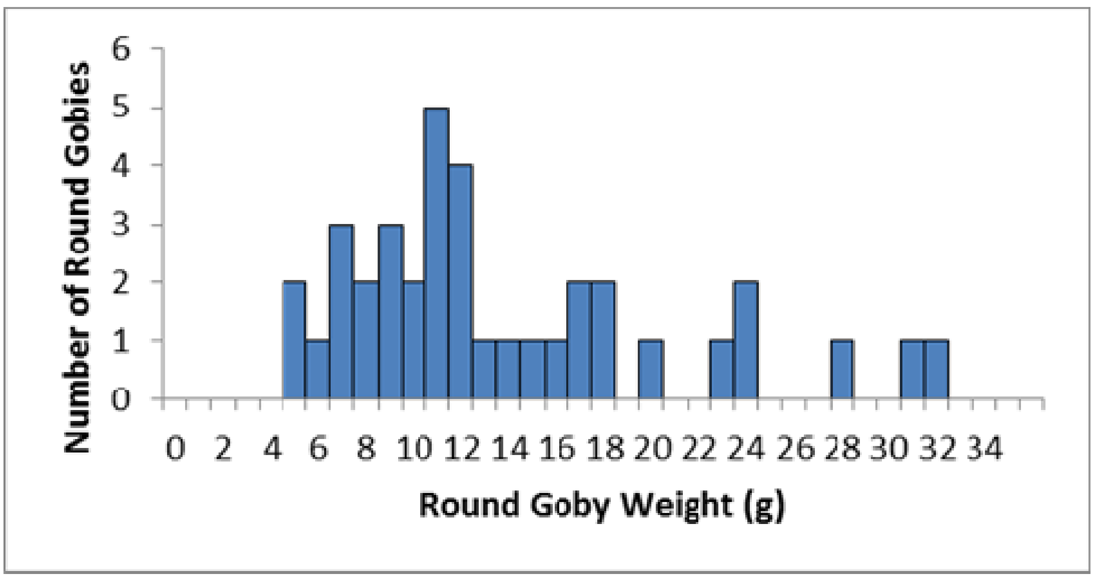
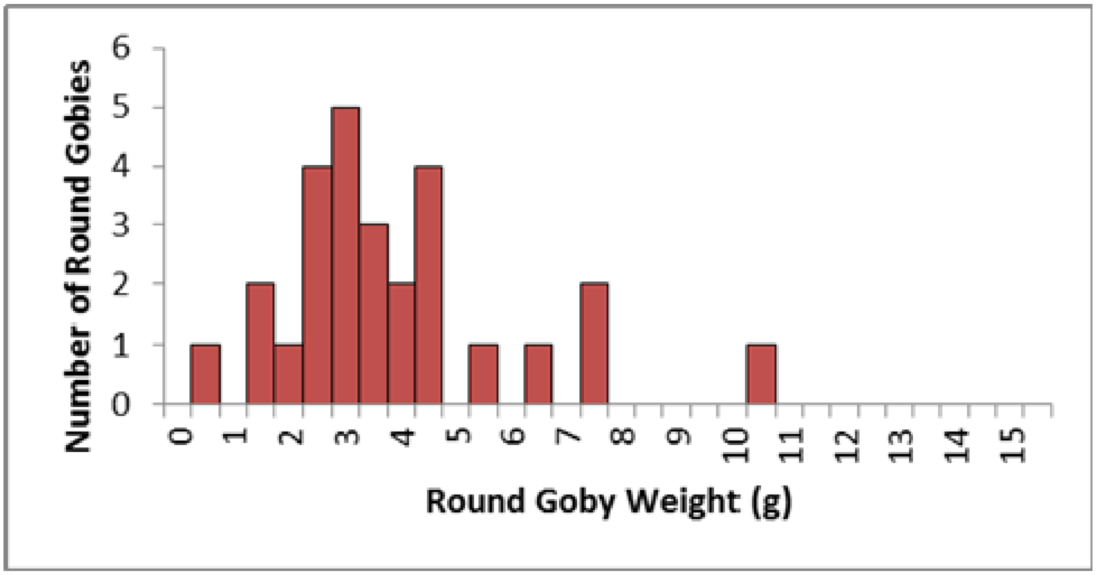


Figure 19. A histogram of the frequency of fish from Lake Michigan at a specific weight.



<u>Figure 20.</u> A histogram of the frequency of the round goby from the Lower Fox River at a specific weight.

Growth Curve

The fish collected from Lake Michigan tended to represent a higher spectrum size range of the growth curve than gobies from the Lower Fox River (**Fig. 21**). The round gobies collected from Lake Michigan are more dispersed in their length-weight relationship than those from the Lower Fox River. The length-weight trends appear to mirror each other and represent similar growth between the two habitats; however, the Lake Michigan specimens seem to gain weight at shorter lengths than the individuals collected from the Lower Fox River.

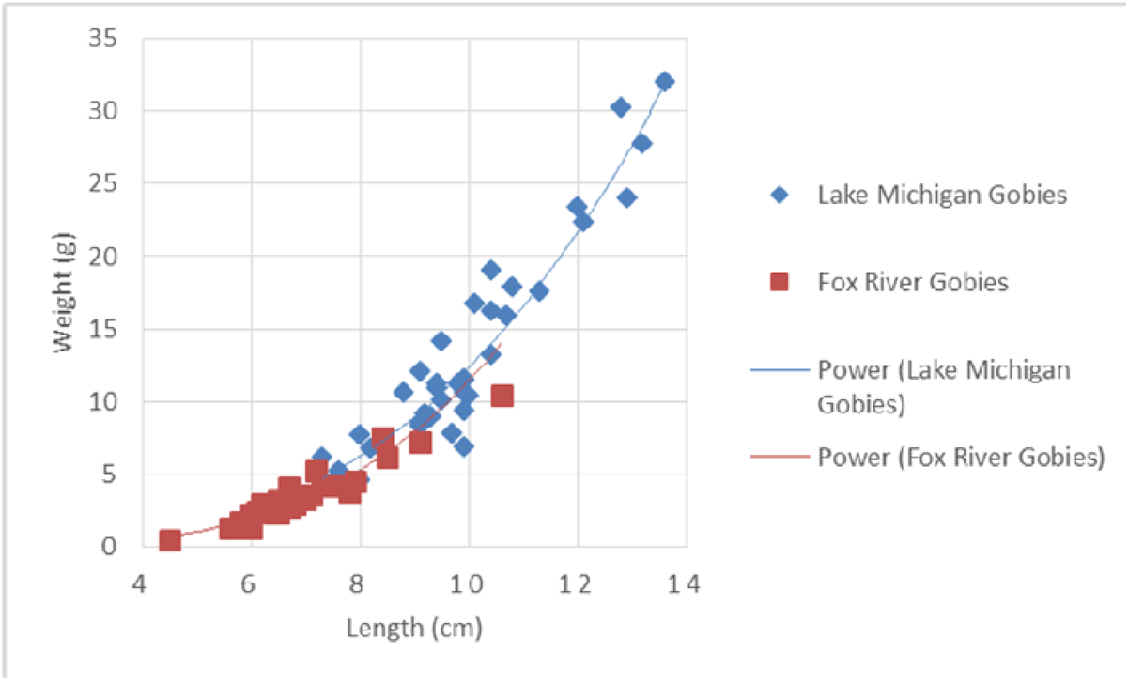


Figure 21. A length-weight scatter plot showing the growth trend in round goby from two habitat types.

Condition Factor

The round gobies collected from Lake Michigan on average had a higher condition factor than specimens collected from the Lower Fox River (**Fig. 22 & 23**). The fish collected from Lake Michigan have a condition factor ranging from 8 to 17.5. Most fish in the lake habitat have a condition factor between 12 and 13.5. The fish from the Lower Fox River have a condition factor ranging from 6 to 15.5 with the largest frequency of fish being 10.5. We found statistically significant differences in both the t-test and Mann-Whitney U test we performed comparing the condition factor of the gobies from the different habitats (t-test P=5.03865E-06/ Mann-Whitney U P=1.79523E-05).

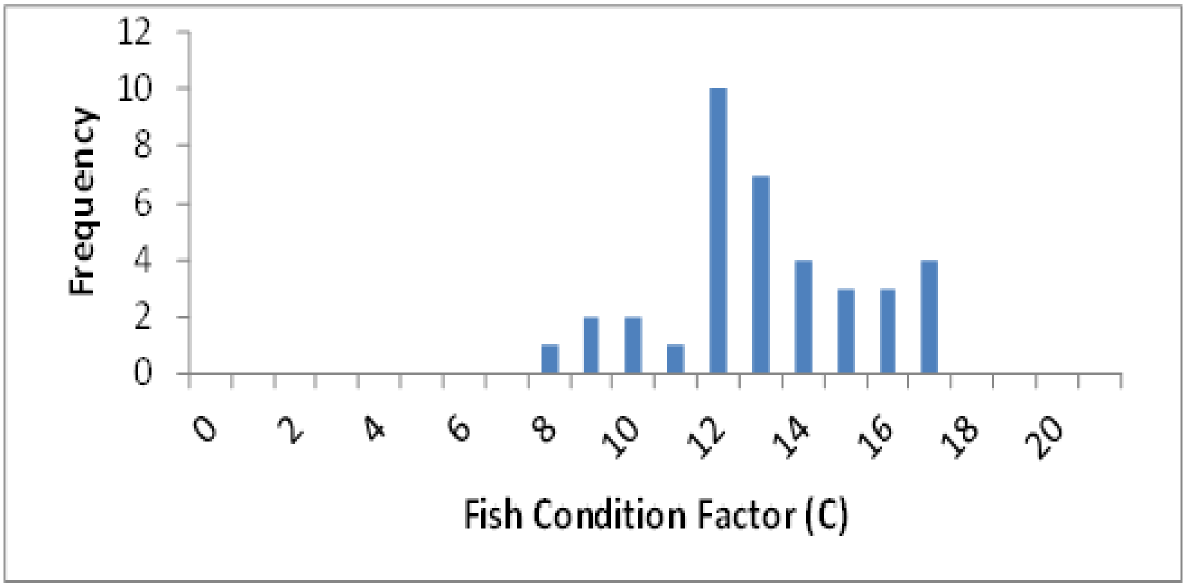


Figure 22. A histogram of the frequency of round goby at a certain condition factor in Lake Michigan.

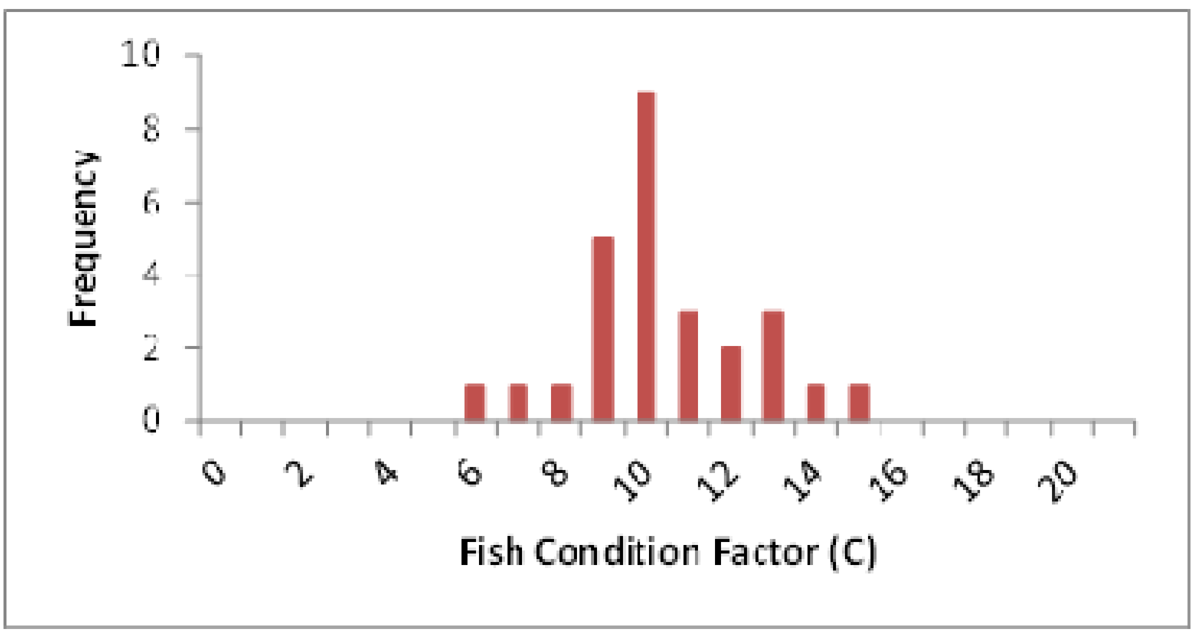


Figure 23. A histogram of the frequency of round goby at a certain condition factor in the Lower Fox River.

Age

The age distributions between round gobies from the river and lake habitat were also different from one another (**Fig. 24 & 25**). Round goby collected from Lake Michigan tended to be older, with the most frequent age group being age 3 (**Fig. 24**). There were no gobies collected from Lake Michigan that fell into the age 0 category and only one goby was present from the age 1 group. The round gobies collected from the Lower Fox River had a younger trend in age distribution with most gobies being between the ages of 0 and 2 (**Fig. 25**). There were no gobies collected from the Lower Fox River that were age 4.

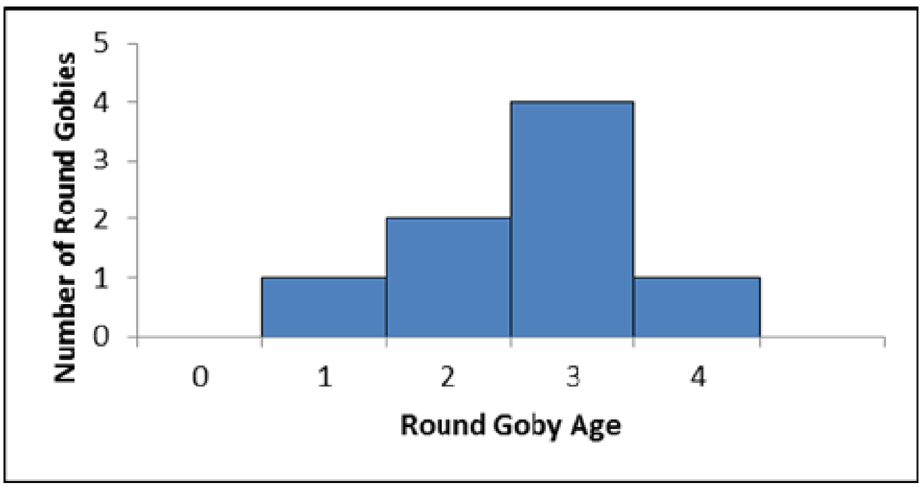
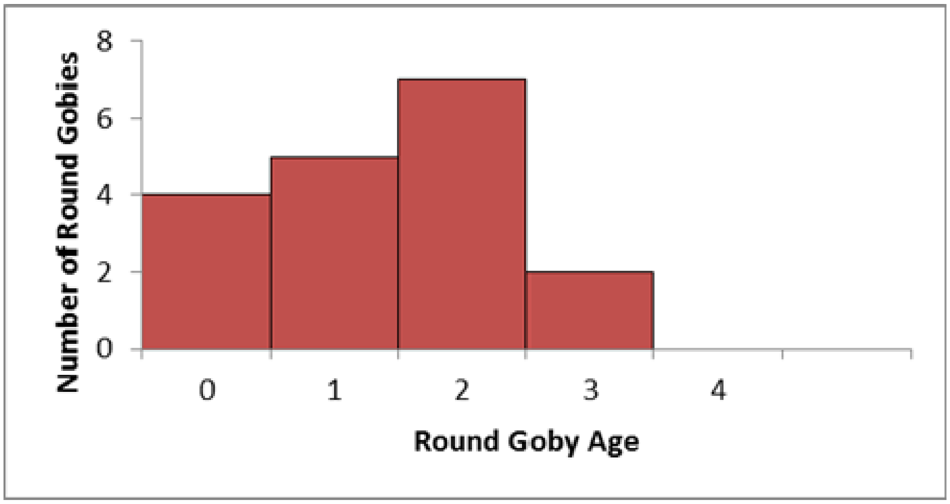


Figure 24. A histogram of the frequency of round goby at a specific age in Lake Michigan.



<u>Figure 25.</u> A histogram of the frequency of round goby at a given age in the Lower Fox River.

Gobies from Lake Michigan showed a faster rate of size development with age than individuals collected from the Lower Fox River (**Fig. 26 & 27**). Round gobies from Lake Michigan tended to have a closer length relationship with river gobies at a given age. At age 1 lake gobies are only slightly larger the river gobies and the same is apparent at age 3. There is a difference of almost a centimeter between lengths of fish from each habitat at age 2. The fish from the lake habitat develop a greater weight at a given age than individuals from the river habitat. The overall trend between the weight and age relationship shows that as age increases the difference in the rate of weight development increases as well. This trend means that as Lake Michigan gobies age they tend to increase the amount of weight gained at a higher annual rate than fish from the river.

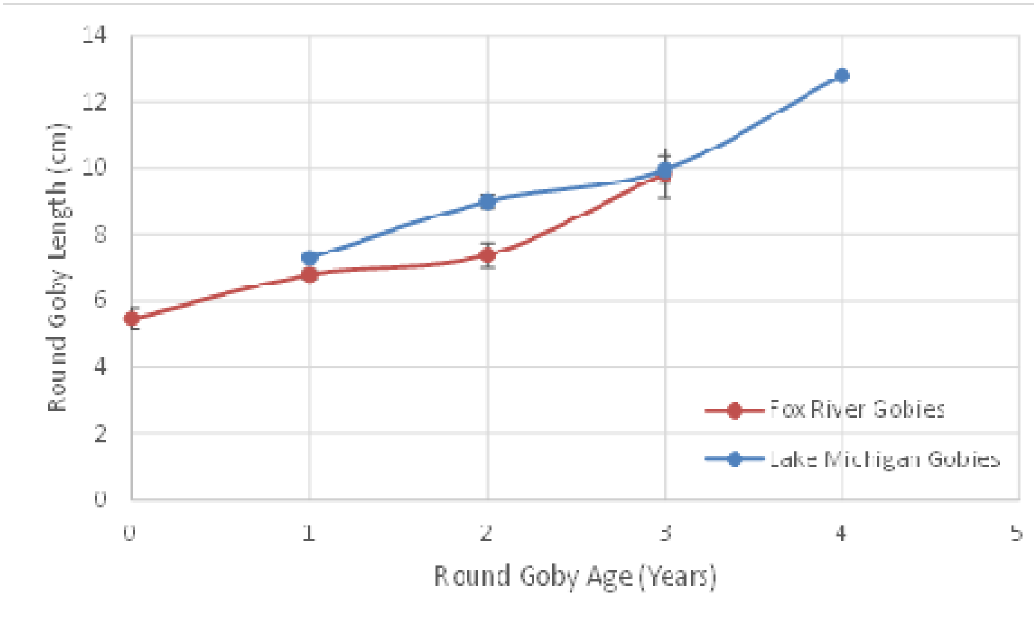


Figure 26. A growth trajectory for length at a given age, from both habitats, based on the average length of an age group.

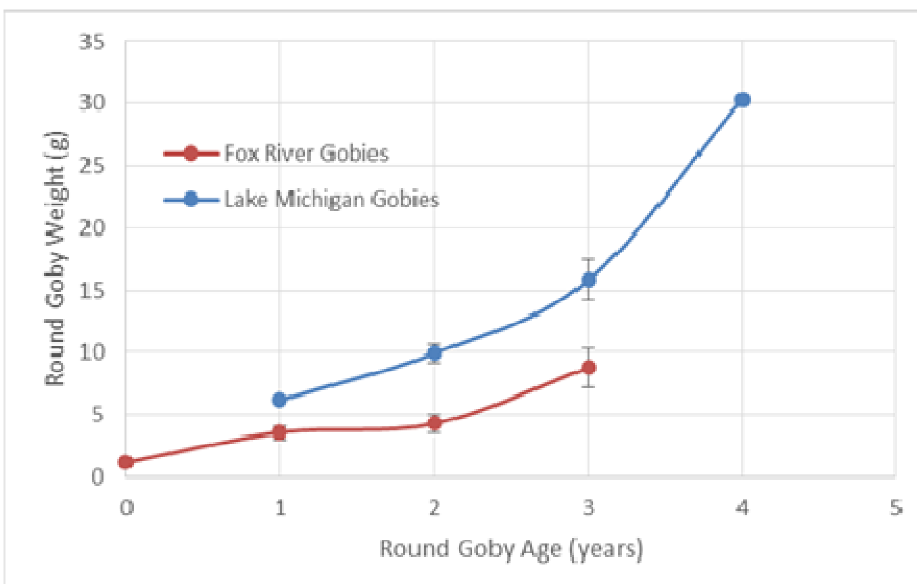


Figure 27. A growth trajectory for weight at a given age, from both habitats, based on the average weight of an age group.

Discussion

Results Comparison

The size of the gobies that we collected from both habitats somewhat parallels size data collected from similar habitat types. Grul'a et al. (2012) notes that the largest round gobies collected from the Detroit River reached 12.4 cm in total length and 18 cm in the Great Lakes (Grula, Balazova, Copp, & Kovac, 2012). The largest round goby that we collected from the Lower Fox River was 0.9 cm smaller than the largest individual recorded from the Detroit River (**Fig. 18.**). Similarly, the largest individual collected from Lake Michigan in our study was 3.5 cm shorter than the largest mentioned by Grul'a et al. (2012).

The length comparison between the populations was unique compared to the results that Grul'a et al. (2012) noted in their study. In their study, individuals from freshly invaded habitats grew in length at a faster rate than the individuals from longer established habitats. We did not see this trend in our study, but instead saw individuals from established habitats grow faster than newly settled individuals at age 2 (**Fig. 26**). At ages 1 and 3 we saw very similar lengths between the two populations; however, the established individuals were still longer on average (**Fig. 26**).

The individuals collected from the established area were in general larger in terms of weight than those from the recently introduced habitat (**Fig. 27**). When the average weight of fish at a specific age from both habitats was compared round gobies from Lake Michigan were much heavier (**Fig. 27**). The difference in weight at a given age was much more severe than the difference in length. The variations seen in weight could be due to changes in resource availability or allocation that will be discussed later.

The oldest individual in our sample was collected from Lake Michigan and was 4+ years old. This corresponds to the oldest age noted for invasive populations by Grul'a (2012) in the Detroit River. In general the age of the two populations we examined had some overlap between the ages of 1 and 3; which allowed us to make direct comparisons between the individuals at these ages (**Fig. 24, 25, 26 & 27**). The fact that there were no age 4 fish collected from the newly invaded habitat could be due to a variety of reasons and the same could be said of the lack of age 0 fish in Lake Michigan. Fish in these age groups were likely not present or collected through the sampling methodology used.

Environmental Factors

Our results showed a significant difference in size between round gobies from sites along the Lower Fox River and individuals collected from Green Bay, Lake Michigan. This was observed for length, weight and condition factor of the gobies examined. Gutowsky and Fox elude to density, biotic factors, and abiotic factors being key to the life-history traits of the round goby (Gutowsky & Fox, 2012). Grul'a et al. (2012) notes that cases like this may be due to changes in ontogeny. The changes in life history traits between different populations of the same species is noted by Gutowsky and Fox (2012) as, "providing an example of how an invasive fish can exhibit life-history variation related to the stage of invasion." Changes in life history is a particularly interesting theory when discussing the invasive potential of an organism. Given the different observations of Gutowsky and Fox (2012) and Grul'a et al.

(2012), I will address both ideas about what is responsible for the life-history variation we observed.

The primary cause of changes in life history traits between populations of species are density-dependent factors, according to Gutowsky and Fox (2012). Density-dependent factors represent any element of an organism's life that is affected by the proximity and size of the rest of the population. In their study, round gobies collected from the invasion front are larger than fish collected from the core site. This is noted as being the result of intense intraspecific competition for resources and preferred habitat types near the core, while the fish on the edge of the invasion front are larger because they are not as affected by competition (Gutowsky & Fox, 2012).

Density-dependent factors are probably not as direct a contributor to the variation in size amongst the gobies surveyed in the two habitats from our study. The size data we collected showed the opposite pattern between gobies from the established versus the more recently colonized habitats when compared to that of Gutowsky and Fox (2012). In our case, round gobies from the core habitat, Lake Michigan, are statistically larger in length and weight than those that were collected from the Lower Fox River. The round goby was first observed in the middle region of Green Bay in 1998 (Lederer et al., 2006), while colonization of the Lower Fox River has occurred only since 2006 (Kornis & Vander Zanden, 2010; B. DeStasio, unpublished data). The results of our study suggest that gobies in this system were not as susceptible to density-dependent factors because individuals collected from the original habit of Lake Michigan habitat were larger. This observation does not support the conclusions of Gutowsky and Fox (2012) in which gobies in the densest habitat were smaller. Part of the explanation for this difference could be that our habitats were more productive and round goby were not food limited in these locations.

The exclusion of density-dependent factors as a cause of variation in the life-history traits of these populations led us to look at the next potential cause for the differences observed in our study, which is variation in biotic factors between the two habitats. Variations in food availability is potentially the most expected contributor of differences in the life-history traits of the two populations. Grul'a et al. (2012) touches on the ability of fish to react to acute variations in food availability by decreasing or stopping growth when it is not available. Our results could be showing a variation in the availability of food resources between the two habitat types within our system, which would explain why we see a significant difference in size between the two populations.

The problem with trying to cite food availability for the observed variation in life-histories between the two populations is a lack of data on native benthic macroinvertebrates. We did not conduct diet analysis of round gobies obtained in this study to see if there was a difference in stomach content or fullness. Our sampling methodology involving minnow traps baited with chicken liver would have skewed any results from stomach content analysis as well. Similarly, we did not attempt to quantify the abundance of benthic invertebrates in these two habitat types or compare the available food resources. Some previous work on this topic has been conducted, and suggests that food availability in stream versus lake habitats may be important for determining the success of round goby (Kornis et al., 2012). Similar studies on the effects of the introduced round goby on the benthic macroinvertebrate community have also been carried out by Lederer in Lake Michigan (Lederer, Massart, & Janssen, 2006). This study showed that the introduction of the round goby caused a decrease in prey macroinvertebrate abundance in Lake Michigan. However, this is counter intuitive to the observed size results. The lack of prior studies on the variation in benthic macroinvertebrates between the Lower Fox River and Lake Michigan make it difficult to accurately assess food availability between these two habitats. Stomach content analysis and sampling of benthic macroinvertebrates in these habitats may provide a better idea about how influential biotic factors are to round goby development and would be a good extension of these studies.

Without any conclusive data about the effect of biotic factors on the variation in life-history traits between these two habitats I'll switch focus to abiotic factors as a potential determinant of fish development. Habitat selection can have a drastic effect on two different populations. Grul'a et al. (2012) noted that water temperature is a factor that affects the formation of annuli as well as the rest of the body. Citing an incident of flooding and low temperature in the Danube River in 2009, round goby individuals experienced shorter growth seasons and grew to smaller sizes (Grula et al., 2012). Looking at previous trends we examined abiotic factors such as the tendency of river and stream systems to experience faster changes in temperature than lake habitats (DeStasio, 2012). The relatively quick changes in temperature in river and stream habitats cause them to be similar to the observed air temperature. The average air temperatures at the Oshkosh airport for the fish growing season (May 1 – Oct. 30) recently have been documented at 16.06°C, 17.98°C and 17.4°C in 2009, 2010, and 2011 respectively (DeStasio, 2012); (NOAA). The changes in documented temperature may have an effect on fish growth in both habitats. In the bay sites used for sampling there has been recent warming due to flooding (DeStasio, 2012). More data analysis from change in temperature during these years would be necessary to reach a conclusion about the effect on the round goby.

Alternative Ontogenies

Besides the major factors that Gutowsky and Fox (2012) note as being the key factors in the variation of life-history traits within a species, I will look at the Grul'a et al. (2012) and their theory of alternative ontogenies and invasive potential. The idea behind the theory of alternative ontogenies is that species will develop unique life-history traits in order to maximize success in a given habitat (Grula et al., 2012). This theory is particularly worrisome when it is associated with invasive potential or the ability of a species to invade and successfully survive in an introduced habitat (Grula et al., 2012). In their study on the age and growth of invasive round goby in the Danube River, Grul'a et al. (2012) observe a similar trend to the one in our study: round gobies in a newly introduced habitat are smaller than those individuals from an established habitat (Grula et al., 2012). The theory of alternative ontogenies is important to explaining the differences in the life-history traits between fish in both habitats. Grul'a et al. (2012) note that round gobies that are found in the invasion front are smaller in weight than the individuals from the same area several years after establishment. Not only did they note that gobies showed a significant difference in weight between being newly invaded and established, but they also noted that recently introduced gobies matured faster than their established counterparts (Grula et al., 2012). From these observations they concluded that the differences in life-history traits could be a result of a shift in the allocation of resources throughout the development of individuals and the population. Variation in the life-history traits of a species may be the result of an adaptive reaction to an unknown environment. The same change in life-history has been seen in two other invasive species, the pumpkinseed sunfish (*Lepomis gibbosus*) and black bullhead (*Ameiurus melas*);(Copp, 2007); (Novomeska, Kovac, & Katina, 2010); (Grula, Balazova, Copp, & Kovac, 2012).

The allocation of resources (in individual populations experiencing variation in life-history traits is rather interesting as well. Grul'a et al. (2012) note that gobies in newly invaded habitats seem to allocate fewer resources to somatic growth and focus on maturation and reproduction. This type of resource allocation creates a life-history structure centered on rapid reproduction over the development and health of an individual. In terms of invasive potential this makes for a highly successful species that can reproduce quickly given the available resources. However, a life-history that works well during an invasion may be disadvantageous when a population has established itself (Grula et al., 2012). Noting that one life-history strategy may not work after a population has established itself, we compared our established Lake Michigan gobies to the gobies in the Grul'a et al. (2012) study. From this comparison we noted that similar to their study the gobies in the established habitat often grew larger in weight faster than their invasive counterparts. The similarity in our observations led us to believe that we were potentially viewing parallel specializations in goby life-history traits between established habitats.

A high ecological tolerance alone may not be enough to allow a species to become a successful invader as Kovac (2006) notes. Citing the observed plasticity displayed by our study as well as Grul'a et al. (2012) and Kovac (2006) the round goby as well as several other invasive species may be successful because of flexibility. The ability to switch from a highly precocial lifestyle in indigenous fish to an altricial one to support survival in new habitats may be the observed trend in our study based on the size differences we observed. The trend in invasive fish species to switch from precocial to altricial trajectories has been documented in both Eurasia and North America (Grula, Balazova, Copp, & Kovac, 2012); (Maria & Kovac, 2006). It is likely that previously mentioned variations in life history strategies between newly introduced and established populations of round goby in combination with biotic and abiotic factors represent the variation in size that we observed.

Conclusion

In conclusion, round goby from Lake Michigan and the Lower Fox River show statistically significant differences in size. The observed differences may be the result of one or several factors. We cannot accurately assess the effect of food availability or richness on round goby growth between these two habitats at this time, nor can we examine the effects that temperature has had on their development. Both of these factors are interesting future research directions for this study to continue through.

Based on the similarity to our study and precedent cited from Kovac (2006) and Grul'a et al. (2012) it is likely that round goby in these two habitats are experiencing two different life-histories. The apparent epigenetic switch to altricial life-histories in newly invaded territories can explain why we are seeing smaller fish as far as length, weight, and condition factor. It is noted by both Kovac (2006) and Grul'a et al. (2012) that this may be a response to new habitat through reduced specialization. If this is the case with our observed data it would also shed light as to why we are seeing larger gobies in Lake Michigan. These gobies would be leading more specialized life-histories resulting in resource allocation to somatic growth and the observed size in this study.

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